CCE Inlet Wind Tunnel Experiments

Combined Cycle Engine (CCE) Mode Transition

Fundamental Aeronautics – Hypersonic Project

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Cleveland, Ohio

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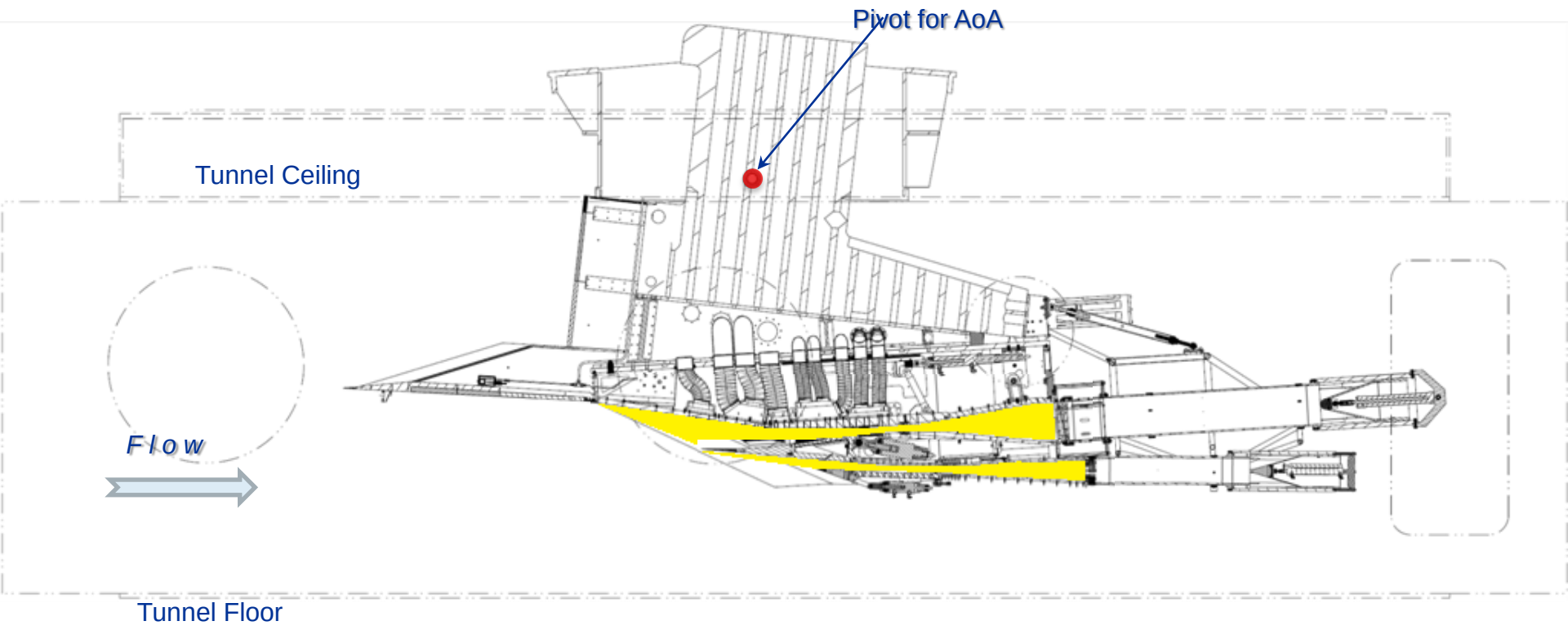
CCE-LIMX Model Features



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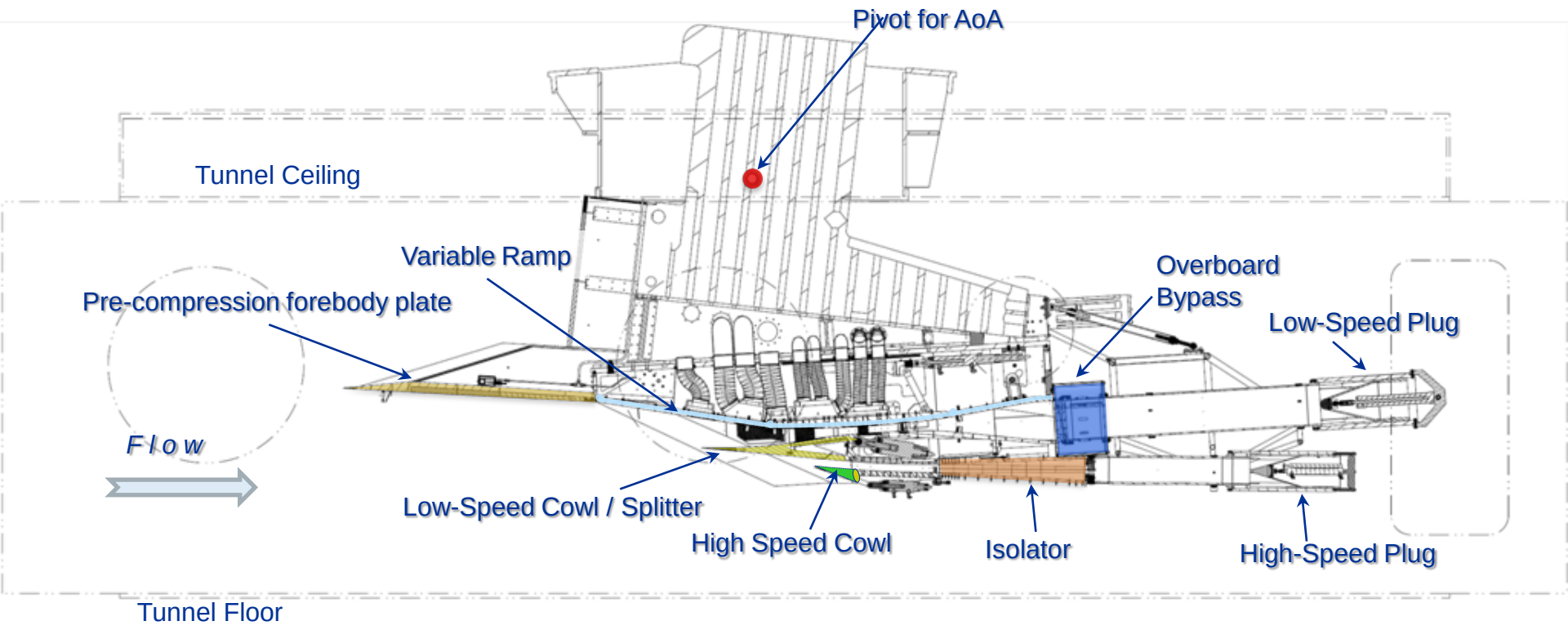
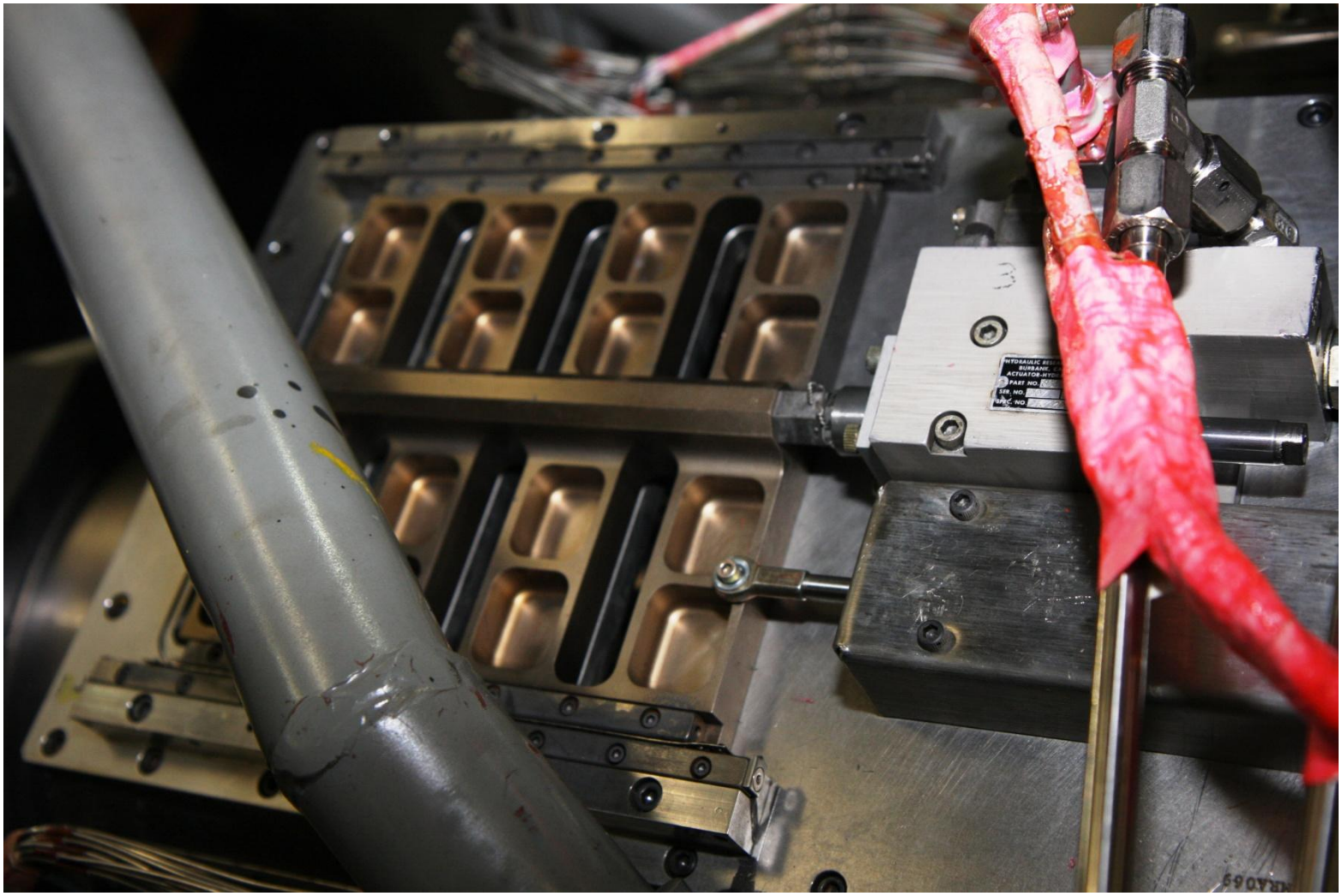


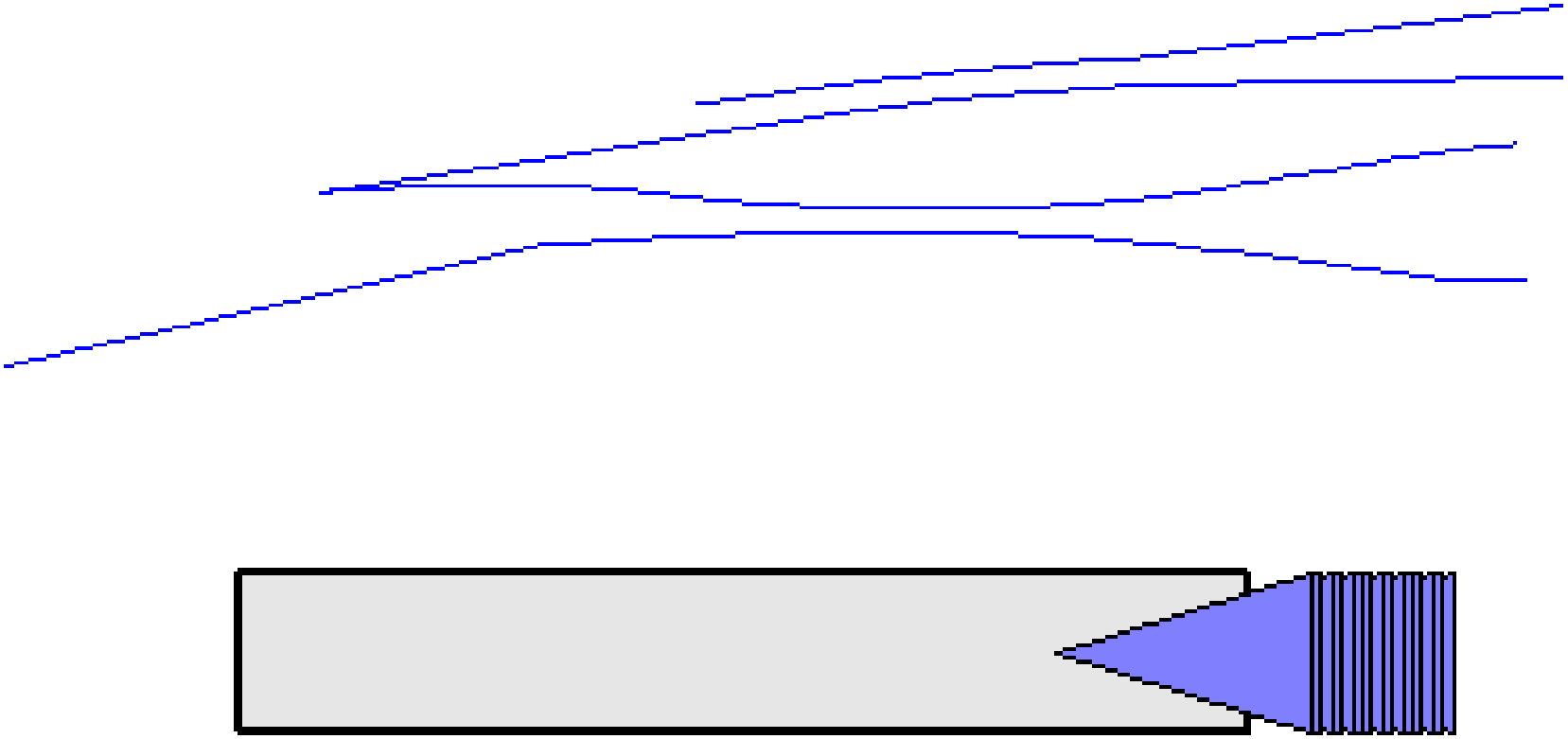
One of Four Bypass Doors



CCE Inlet Wind Tunnel Experiments

- CCE-LIMX hardware testing is conducted in the following four phases:
  - Phase 1 Inlet characterization and performance testing
    - Static inlet operating points
    - Mode transition schedule
  - Phase 2 System identification
    - Step response analysis
    - Sinusoidal sweep response analysis
  - Phase 3 Controls testing
    - Disturbance rejection testing
    - Controlled mode transition
  - Phase 4 Propulsion system testing
    - Turbine engine for LSFP
    - Dual-mode combustor for HSFP

Phase 1: Inlet Characterization and Performance Testing



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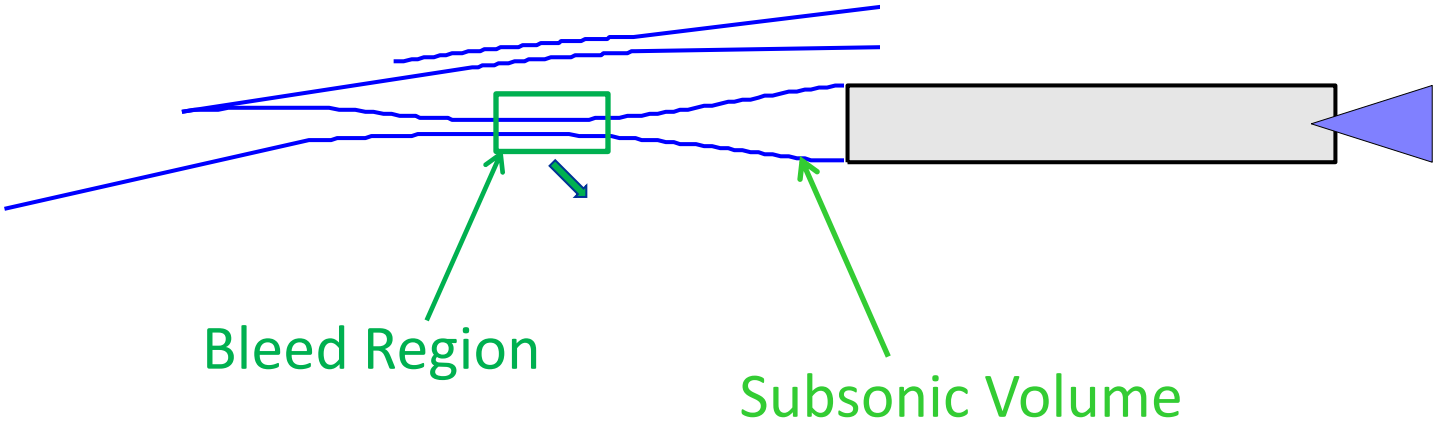
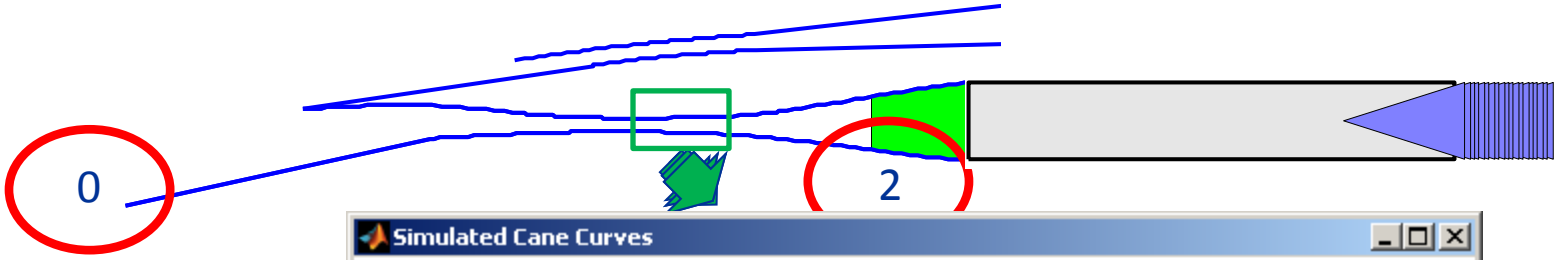
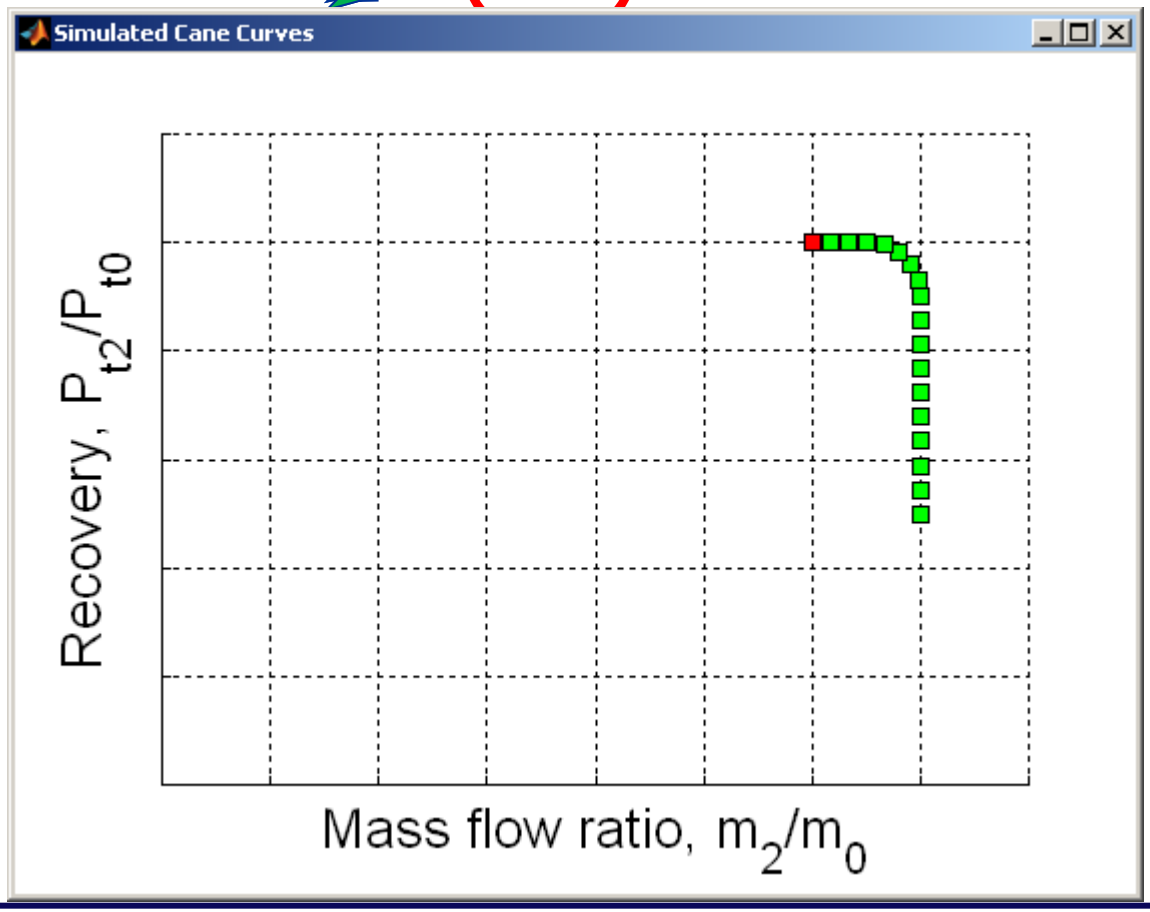


Phase I: Inlet Characterization and Performance Testing





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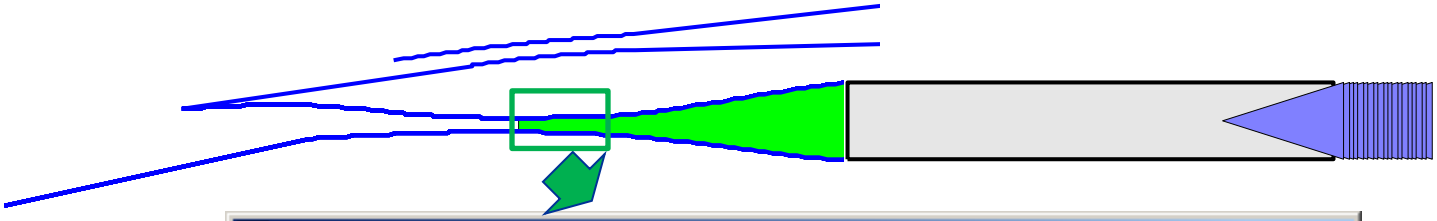

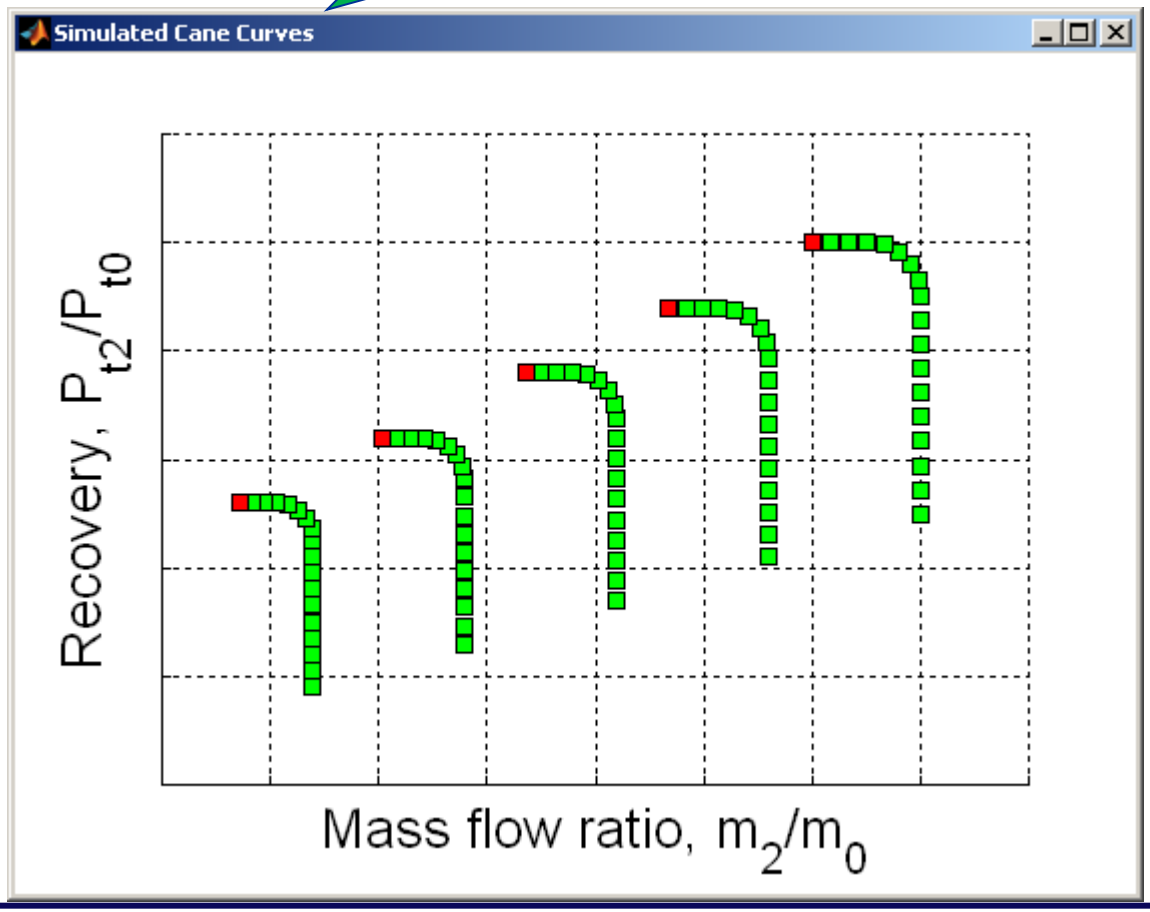

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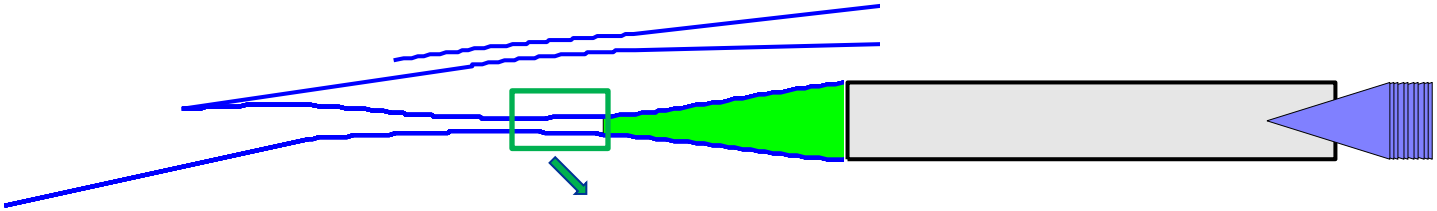
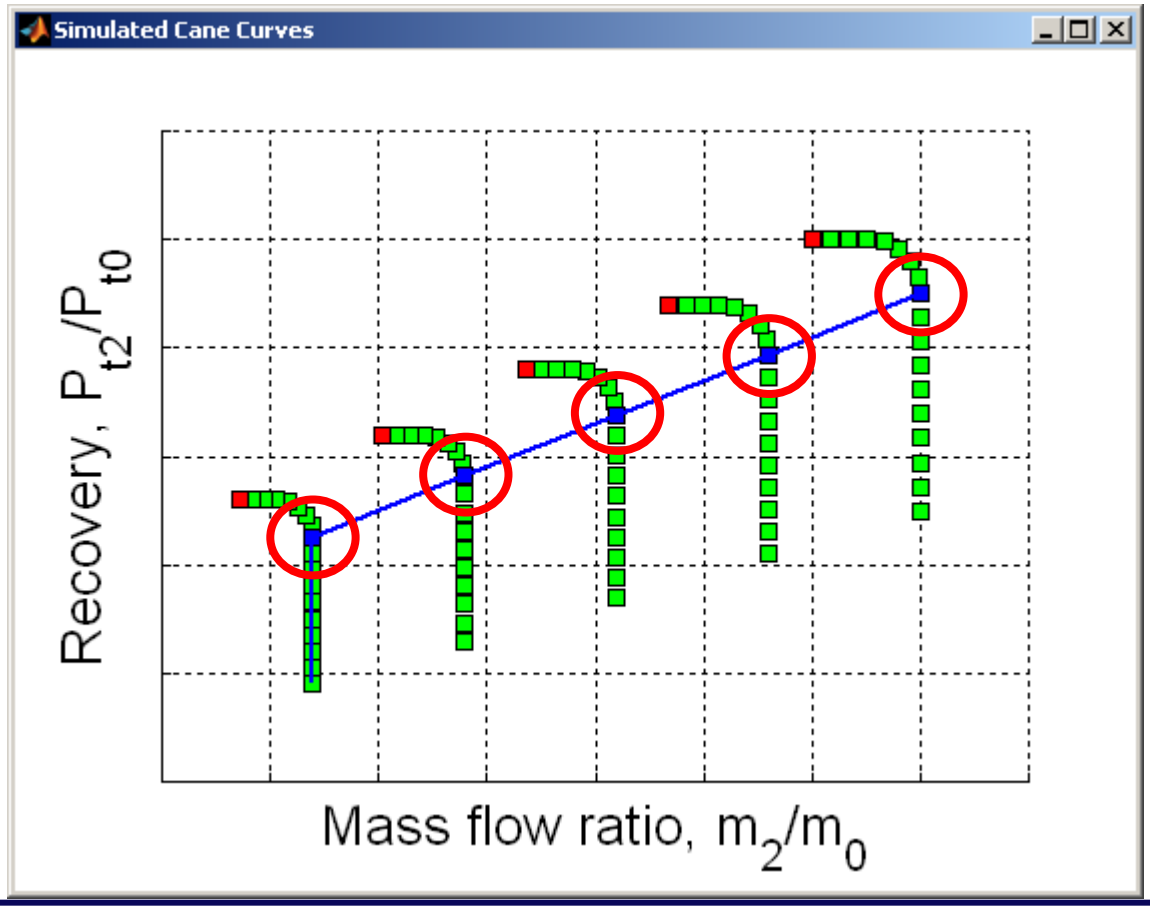
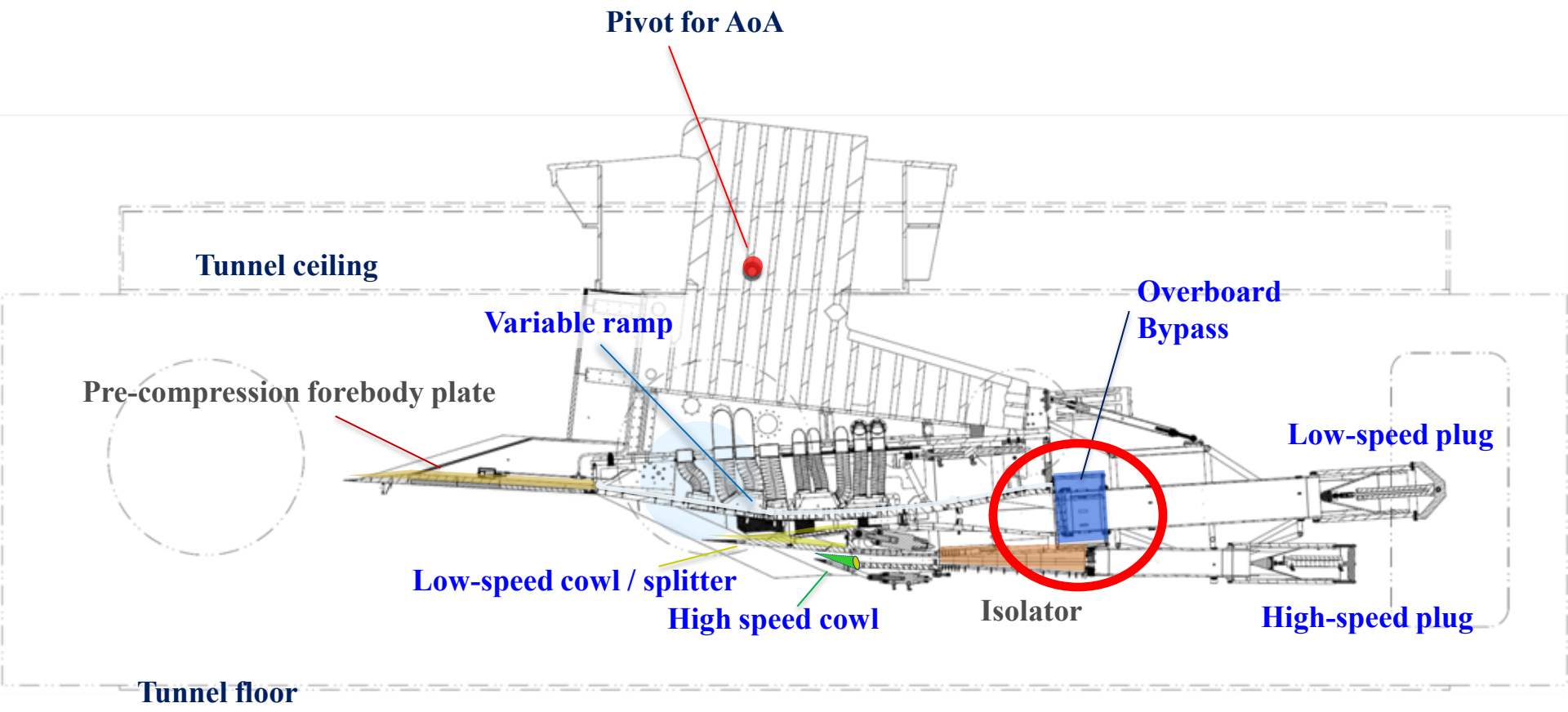




Controlling The CCE-LIMX



Design a Controller

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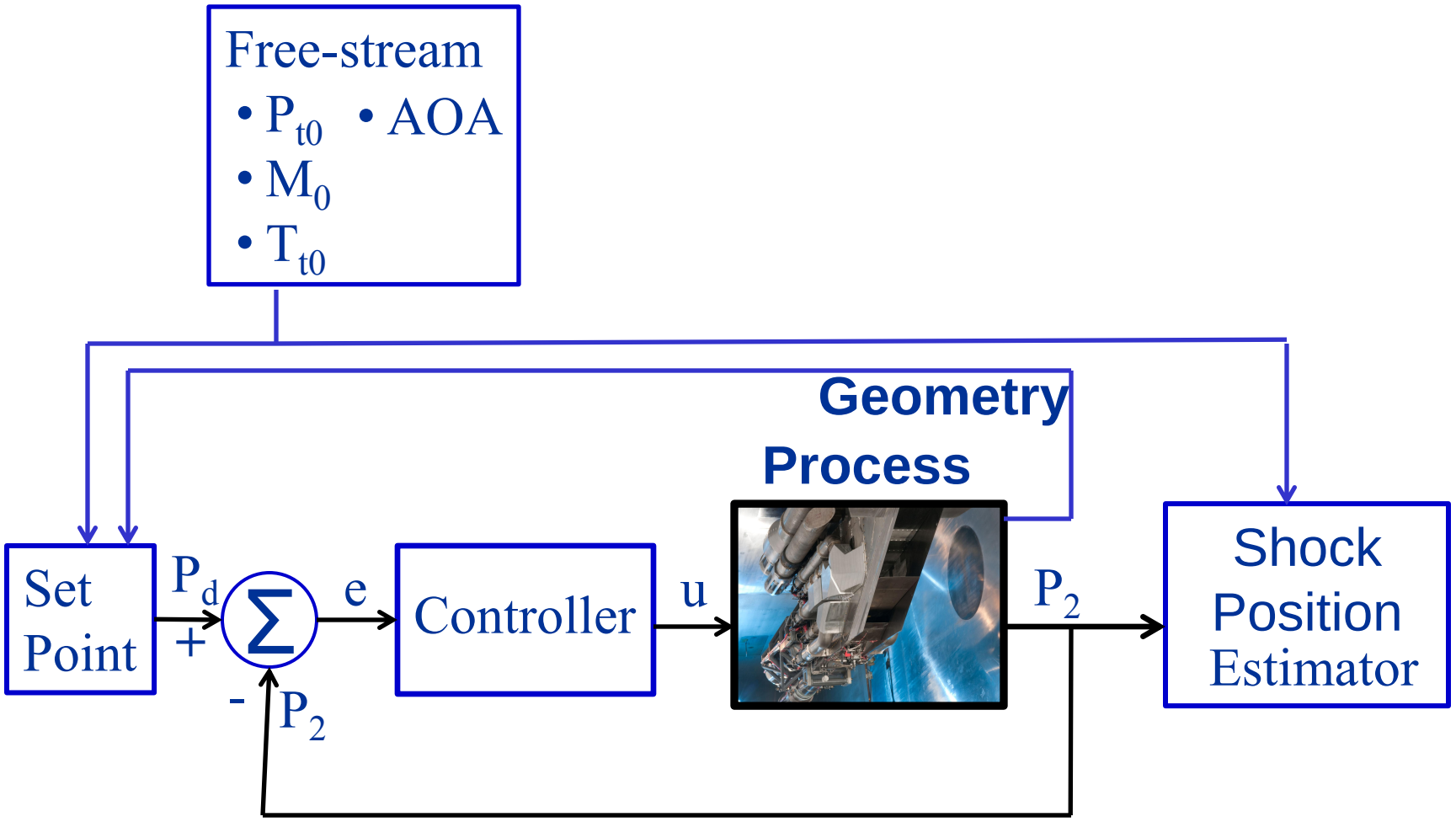
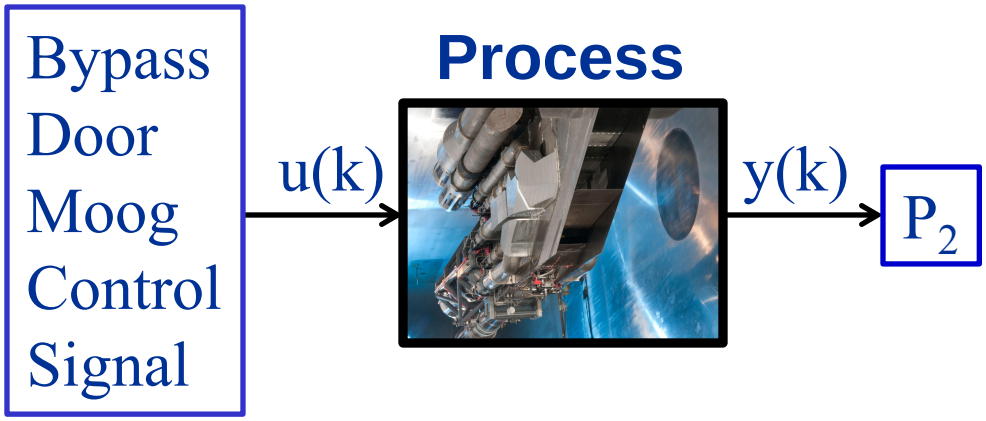


First, Design the Model



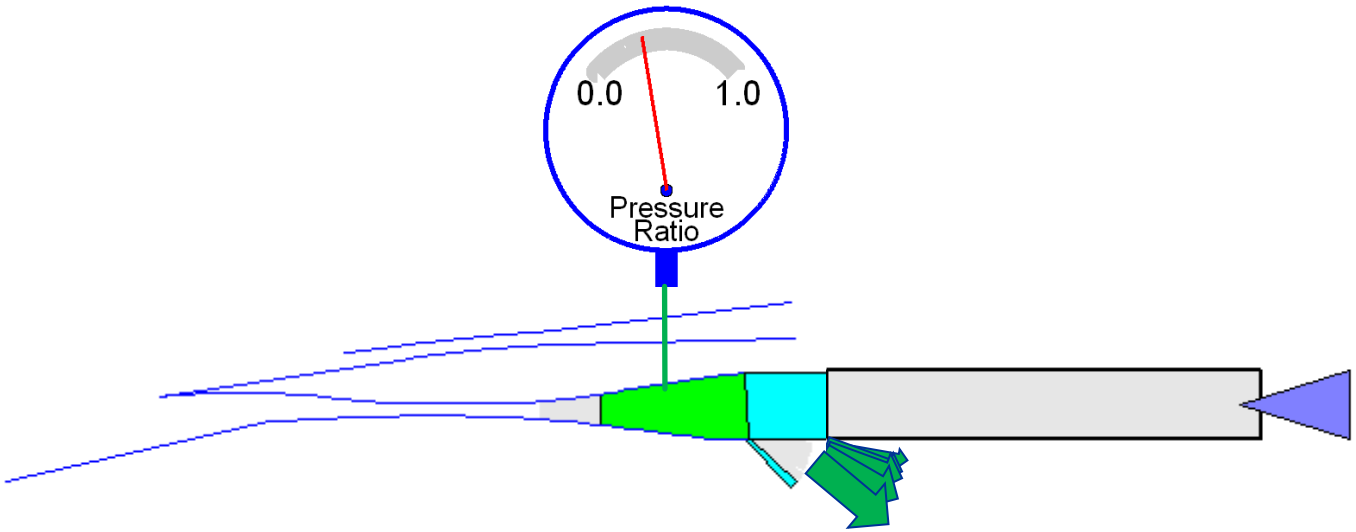
Process assumptions:

Sufficient control design simulation can be captured in a linear computational autoregressive control model.

Autoregressive model:

$$y(k+1) = a_0y(k) + a_1y(k-1) + \ldots + a_ny(k-n) + b_0u(k) + b_1u(k-1) + \ldots + b_nu(k-n)$$

Stimulate the Process



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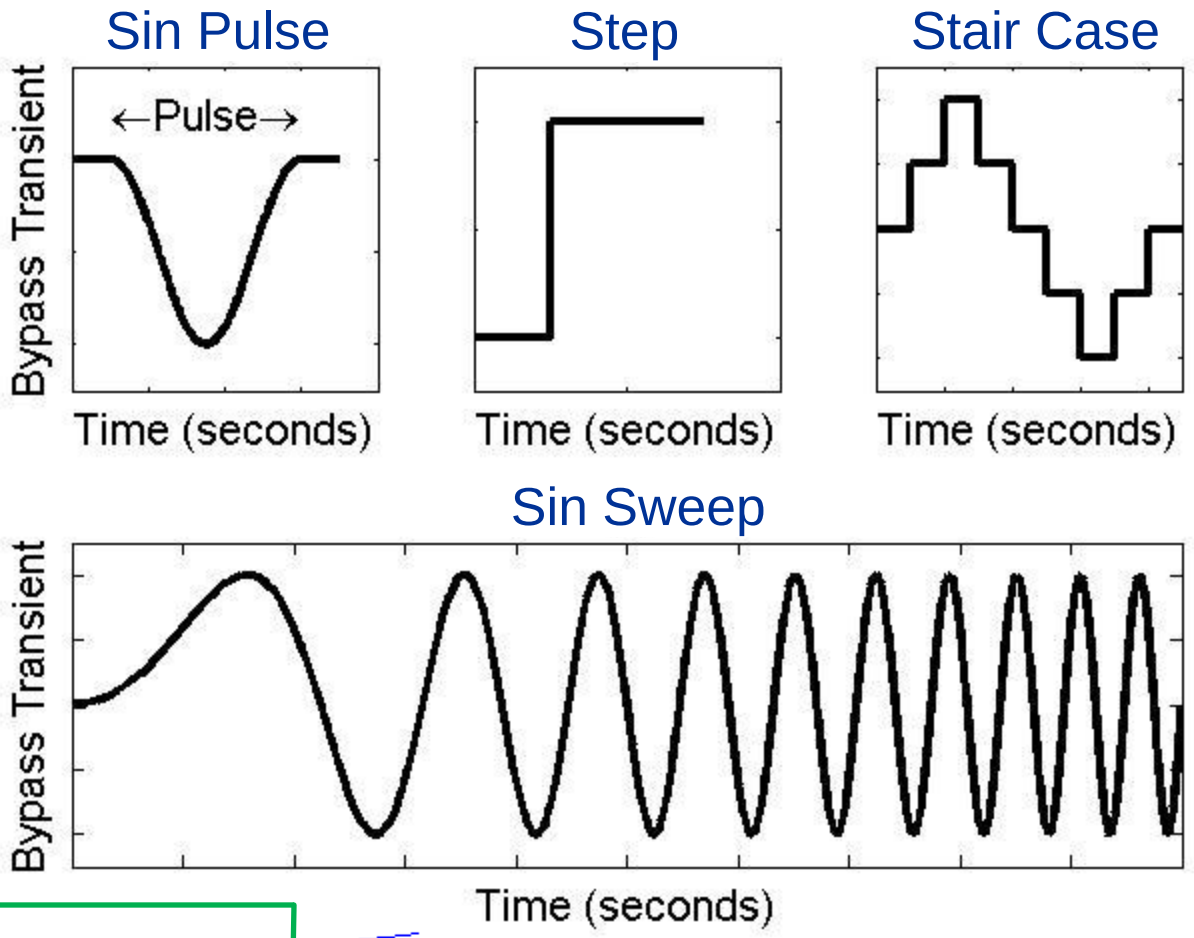

GNC Phase 2 Accomplishments

- Experiment data is ITAR restricted
- Test matrix status Phase 2 Mach 4
  - 642 Experiments identified, ~89 hrs
    - Main (LST1 and HST1) schedule—506 experiments, ~49 hrs
    - First alternate (LST1 and HST2) schedule—68 experiments, ~20 hrs
    - Second alternate (LST2 and HST2) schedule—68 experiments, ~20 hrs
  - Reduced Matix—393 Experiments selected, ~29 hrs
    - Main schedule—378 experiments completed, 38.25 hrs
    - Alternates—0 experiments completed
  - Experiments:
    - Step, Sinusoidal Sweep, Sustained, Sinusoid
    - Staircase, Transient Stability Index (Tsi),
    - Unstart, Buzz, Restart
- Test window: 8/29/2011 – 10/19/2011
- 11 run nights (data collection)

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International Traffic in Arms Regulation

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SysID Rack Performance

- Calibrations in parallel with 10- x 10-foot facility calibration operations.
- Control transfer from facility to SysID Rack and back
  - Small changes in actuator positions due to discrepancy in interpreted actuator positions—insignificant.
    - We had exposure to feedback signals in EU,
    - Better to match voltage signals applied to the controller.
  - Verified SysID Rack controllability prior to facility pump down
  - Verified SysID Rack data acquisition performance while facility pump down.
- Data acquisition and experiment control performed flawlessly

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GRC 10- x 10-foot SWT

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SysID Rack Performance

- Host Laptop II choked on data transfer to host from target—about 4 events
  - Control transfer back to facility
  - Reboot SysID Rack (about 25 min turn around).
  - Enabled a few Phase I type experiments during down time
  - Issue resolved by replacing Host II with Host I.
- Data saved in multiple locations
- Data reduction computer and tools worked flawlessly

Hypersonic TBCC Controls Team
Future Paths

- Continue CCE Phase 2 testing
- Reduce Phase 2 data to control design models (CDMs)
- Compare physics based computational models against CDMs.
- Design control algorithm for maintaining desired pressure recovery
- CCE-LIMX Phase 3 and 4 testing (if funding becomes available)
  - Test controller on physics based computational models
  - Buildup SysID Rack to support Phase 3 experiments
- Investigate control applications for dual-mode scramjet engine flow paths.

Summary

- Well underway to meeting Phase 1 and 2 objectives:
  - Completed:
    - A control system, hardware and software, was designed to demonstrate inlet mode transition.
    - System identification experiments were designed to study the dynamic issues associated with inlet mode transition.
    - A control system was designed, hardware and software, to conduct the system identification experiments and record the experiment data.
    - System identification experiments at Mach 4 mode transition operating points.
  - Underway
    - Dynamic analysis of the system identification experiment data
      - frequency spectrum of interest for active control
      - Experiment based control design model (CDM) development
    - Preparing physics based models to simulate dynamics of inlet mode transition (validation).

Summary

- Well underway to meeting Phase 1 and 2 objectives:
  - Underway (continued):
    - Designing controllers based on:
      - experimental data
      - physics based computational models.
    - Testing controller algorithms on physics based computational models.

End of CCE Wind Tunnel Experiments

Discussion Guideline

Topic:

- Are we working on the right controls/diagnostics technologies w.r.t. project objectives?

- Do we have the right approach?

- Are we appropriately disseminating information on our efforts and the progress being made?

- Are there any other efforts ongoing that we can leverage?